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On some aspects of marginal cyclones

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सार — बहुत कम उष्णकटिबंधीय आवर्त भयंकर चक्रवात की तीव्रता तक पहुंचते हैं, जबकि उनमें से कुछ सीमांत चक्रवात की स्थिति तक पहुंच पाते हैं । उष्णकटिबन्धीय चक्रवात के तीव्रीकरण को अवरुद्ध करने वाले उद्धृत महत्वपूर्ण कारकों में से एक कारक परिवेश वायुमण्डल का पवन अपरूपण है । जब उष्णकटिबन्ध आवर्त अधिक शक्तिशाली किन्तु अनुकूल कारकों के प्रभाव में आता है तो केवल तब ही तीव्रीकरण अधिक होता है । बहुत से कारकों में से जिनके कारण उष्णकटिबन्ध आवर्त का तीव्रीकरण हो सकता है, कुछ कारक हैं : पश्चिमी द्रोणियों के साथ अन्योन्य क्रिया का प्रभाव और भूमिपात के परिणामस्वरूप बढ़ा हुआ परिसीमा स्तर अभिसरण है । इस शोधपत्र में उपग्रह प्रेक्षित प्रबल अपरूपित वायुमण्डल में विकास के पहलू, पश्चिमी द्रोणियों की भूमिका और तट की ओर बढ़ते उष्णकटिबन्धीय चक्रवात के अस्थायी तीव्रीकरण के बारे में वर्णन किया गया है । अन्ततः वर्तमान में किये जा रहे कार्य में उपग्रह विश्लेषण की सीमाओं से पाठकों को अवगत कराने के लिये उपग्रह इनसैट-1बी आंकड़ों का प्रयोग करते हुए उष्णकटिबन्धीय चक्रवात तीव्रता विश्लेषण में सामने आने वाली कठिनाइयों को बताया गया है ।

ABSTRACT. Very few of the tropical vortices attain the intensity of hurricanes whereas quite a few of them reach up to the stage of marginal cyclones. One of the very important factors quoted often for blocking the intensification of a tropical cyclone is the wind shear of the ambient environment. Only when the tropical vortex comes under the influence of more powerful but favourable factors, does the further intensification take place. Amongst the numerous factors which may lead to intensification of an incipient tropical vortex are the influence of interaction with westerly troughs and increased boundary layer convergence as a result of landfall. This paper describes satellite observed aspects of evolution in strongly sheared environment, role of westerly troughs and temporary intensification of tropical cyclones on approaching a coast. Finally difficulties encountered in the tropical cyclone intensity analysis using INSAT-1B data are highlighted to apprise the readers of limitations of satellite analysis currently being pursued.

1. Introduction

Among the most intriguing problems of meteorology is the problem of tropical cyclones. Since the time immemorial, their genesis and intensification continue to receive the active attention of meteorologists world over. According to Ooyama (1982) speculations and suggestions are abundant, but we lack a clear understanding. However, the tropical cyclone apears to originate in an area of organised convective activity. Gray (1982) has emphasized the role of line convection around the circulation centre in the outer 2°-8° radius belt and quotes D'vorak to confirm that the tropical cyclone development tip-off occurs only when there are curving outer cloud lines. The development usually occurs as enhancement of convection within the curve of innermost cloud band which assumes the shape of vorticity comma afterwards. According to D'vorak (1975) as the cyclone intensifies, the comma head becomes an active Central Dense Overcast (CDO) whose size determines the intensity of the tropical disturbances.

The initial pattern of the tropical disturbance usually depends on the nature of the environment and can have a variety of forms but in the mature stage it is the tropical storm that governs the environment and, therefore, it has the usual shape of intense CDO with the eye inside and spirals outside. The analysis calls for the proper identification of the initial pattern and once it has been ascertained D'vorak's technique visualises a certain rate of intensification depending upon the initial pattern. Very few of the tropical vortices assume the intensity of hurricanes whereas the majority of them finish as marginal cyclones defined as cyclones of intermediate intensity (T 2.5-T 3.5). One of the important factors listed for blocking the intensification of tropical storm is the presence of unidirectional wind shear. When the tropical cyclogenesis proceeds in an area characterised by strongly sheared flows the intensification is hampered and signatures of the evolution is the shear pattern in which the heavy dense overcast appears displaced in the direction of the shear from the circulation centre revealed by cumulus lines in the visible imagery. This has been observed and discussed in Sec. 2. This is mainly because of the advection aloft of heat and moisture from the vertical column over the vortex due to the strong shear. Therefore, this does not ensure the proper coupling between the lower and upper atmosphere required for deepening of the low pressure area. D'vorak (1975) has defined many features for intensification of tropical cyclones as seen in the ongoing changes in the satellite imagery. One of the important factors listed by Riehl (1979) for intensification of tropical cyclones is the interaction with mid-latitude westerlies wherein the

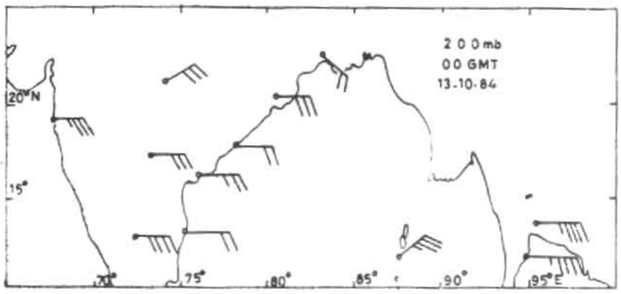


Fig. 1. Upper air winds at 200 mb for 00 GMT of 13 October 1984

cold air sinks very close to the centre of developing cyclones. A case is presented in Sec. 3 wherein the satellite aspects of this intensification are discussed. It is known that almost all cyclones show temporary increase of rainfall on crossing the coast. A few of the disturbances have shown temporary intensification characteristics on approaching land. This aspect is discussed in Sec. 4.

The evolution of a tropical cyclone is characterised by tremendous variability in cloud organisation, particularly in the early stages of cyclone. When such varied types of patterns are observed, enormous difficulties are experienced in tracking disturbances with the help of satellite data and these are summarised in Sec. 5.

2. Shearing flows and their impact on intensification

To illustrate the impact of shearing flows on intensification we shall consider the case of October 1984 cyclone. It formed in the Bay of Bengal as a low pressure area on 11 October 1984 and intensified into a depression on 12 October near 19.0°N, 89.5°E. It crossed the the coast on 14 October as a severe cyclone to the north of Chandbali between 03 and 04 GMT. The satellite imagery of 12 and 13 October is shown in Fig. 2. Fig. 2(a) and Fig. 2(c) represent the infrared (IR) data of 18 GMT of 12 and 13 October and Fig. 2(b) shows the visible (VIS) spectra at 03 GMT of 13 October 1984. As seen in the figure, the signature of this pre-hurricane disturbance comprises of a circular cloud canopy with centre at X, Y and Z at 18 GMT of 12 October, 03 GMT of 13 October and 18 GMT of 13 October 1984. Fig. 2(b) also shows a low level weak circulation just to the east of the overcast at C. In this case, it is the VIS data alone which shows that the overcast is displaced to the west of the low level circulation centre. This defines the shear pattern which is seen in this case only through VIS data and while analysing IR data alone at night the continuity of the centre as seen in the previous time VIS data has to be kept in mind. The characteristic shear pattern in some cases could be discerned through high resolution IR data of NOAA satellites but it is generally missed in INSAT IR field.

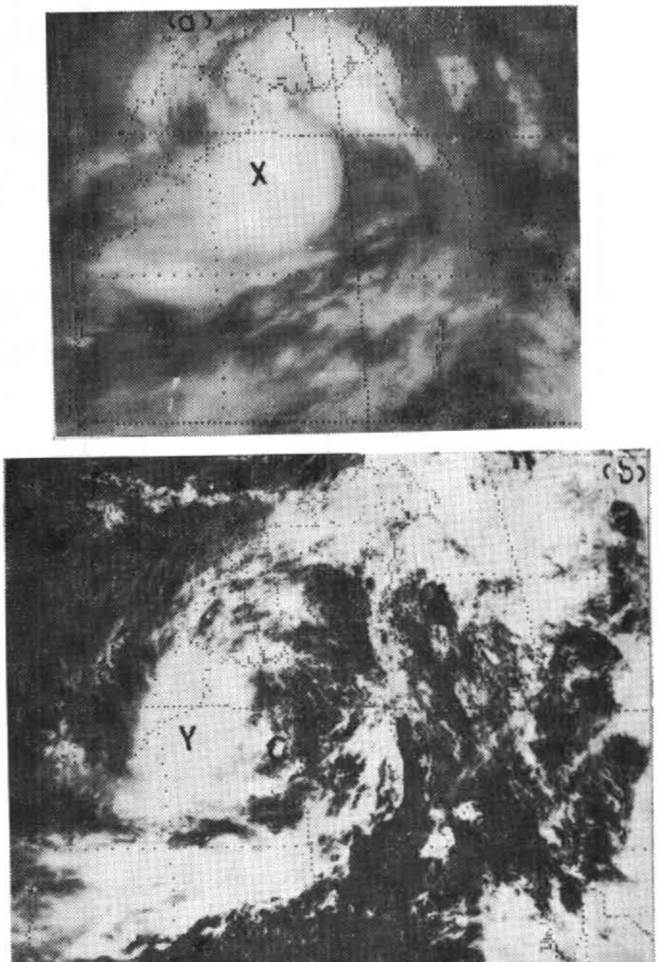
On 13 October the cirrus canopy was more circular with sharper edges and a well defined moat when the intensity had almost peaked. We could not apply the technique of tropical storm intensity analysis to this disturbance very appropriately because the evolution did not display any of the recognisable patterns in a steady fashion. Further, the concept of CDO is usually applicable only for visible data imagery. Curved band concept is valid for both VIS and IR data and no such organised band could be seen. These problems are illustrated in subsequent paragraphs but the evolution nevertheless shows that there has been large fluctuations in cloud pattern and that the intensity is maximum at 18 GMT of 13 October (Fig. 2c). On 13th morning (Fig. 2b) a low level circulation is appearing in the visible imagery away from the dense convection seen during previous night (Fig. 2a) and this circulation is so shallow that it does not get reflected in the IR imagery. The pattern is more or less similar in the case of evolution of most of the storms of October 1985. From this discussion it is very clear that low level circulation is not revealed in the earlier stages in the IR imagery. However, identification of shear pattern in IR may not be difficult. The upshear edge of convection is sharper than the downshear edge and this fact could be used judiciously to discover the shear pattern.

It is interesting to see that winds in the upper troposphere comprised of dead easterlies to the tune of 30 kt at Bhubaneswar and that there was no evidence of prevalence or development of upper air anticyclone which could provide the necessary outflow for further intensification. The upper air chart is reproduced in Fig. 1. The data is very sparse but it is clear that there is no upper air anticyclone. We have no knowledge of wind distribution around the disturbance and attempts could be made in future to derive cloud motion vectors (CMVs) to infer the flow pattern around the disturbances.

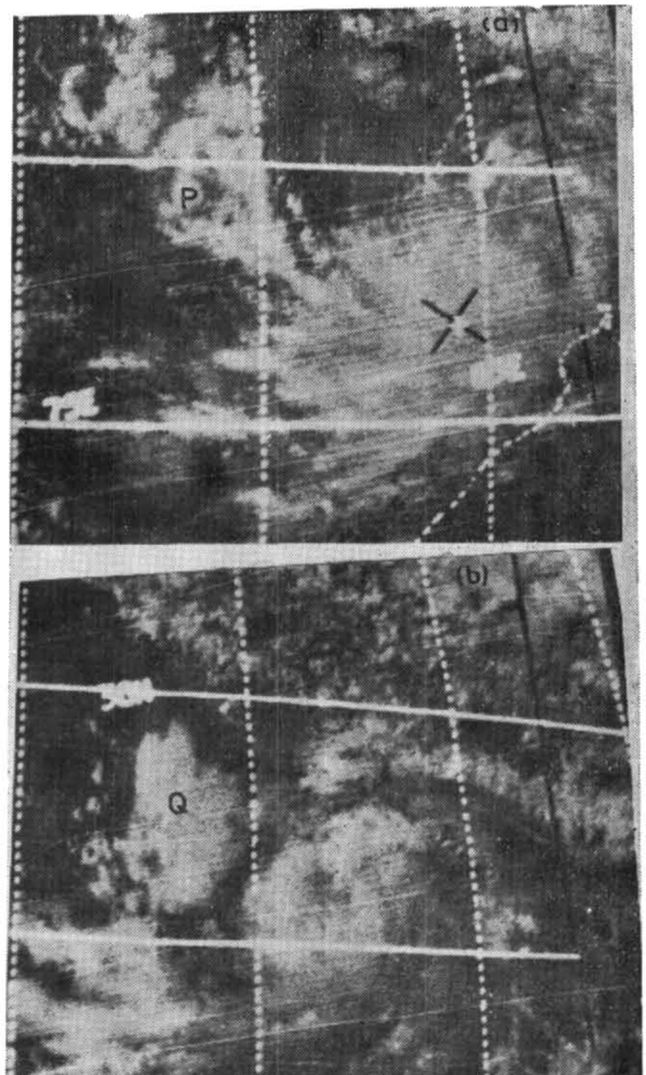
The unidirectional ambient shear is a parameter which is inimical to the process of intensification as it leads to the advection of the heat and moisture out of vertical columns. It is widely believed that the strong environmental shear is one of the very important factors responsible for the complete absence of tropical cyclones in the north Indian Ocean during periods of well developed monsoon over Indian sub-continent. Only during non-monsoon months, when the environmental shear is reduced to half of its value in the monsoon period, does the tropical cyclogenesis occur in the north Indian Ocean. But here again, the remnant vertical wind shear is likely to exercise a powerful control on the evolution of tropical cyclone as is usually experienced in the month of October which may be characterised at times by the strong easterlies in the upper atmosphere when the initial cyclogenesis occurs. This is probably what happened in October 1984 and October 1985. The cyclones in the period 12-14 October 1984, 9-11 October, 13-15 October and 15-17 November 1985 displayed similar changes in organisation and the depth and extent of deep layer convection also changed accordingly. One of the very important observations of this variability was the generally increased and strongly curved deep layer convective mass found usually located to the west of the low level centre revealed by curved cumulus lines to the east in the visible data received during the day time.

3. Riehl's hypothesis for intensification

Riehl (1979) has called for yet another mechanism to account for rapid development of tropical cyclones. He visualises the interaction between the tropical disturbance and mid-latitude westerlies as providing the



Figs. 2(a-c). INSAT 1B imagery showing shear patterns : (a) 18 GMT IR of 12th, (b) 03 GMT VIS of 13th and (c) 18 GMT IR of 13 October 1984



Figs. 3(a-c). Development of cyclone over land in ITOS (VIS). Convective clouds are seen at P and Q as a result of cold air advection aloft : (a) 10*h* 11*m* 34*s* IST on 10th, (b) 10*h* 09*m* 18*s* IST on 12th and (c) 10*h* 06*m* 58*s* IST on 14 September 1970

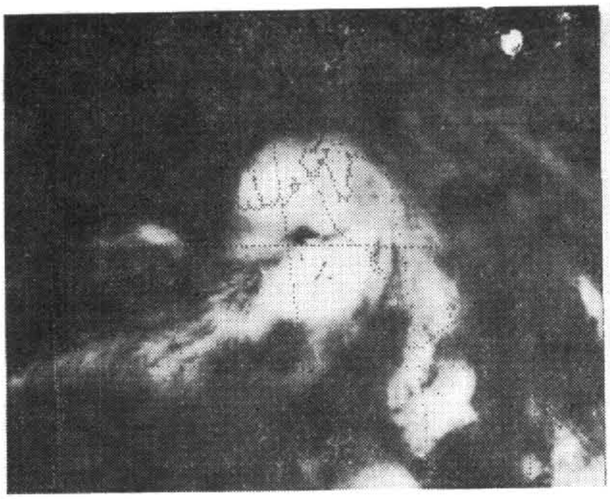


Fig. 4. INSAT 1B imagery at 21 GMT of 24 May 1985 (IR) showing intensification of cyclone at the time of landfall

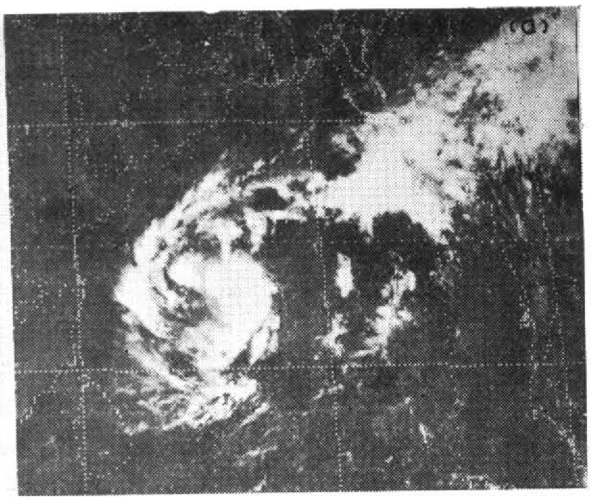


Fig. 5 (a). Variability of cloud pattern (VIS) associated with marginal cyclones at 06 GMT of 15 November 1985

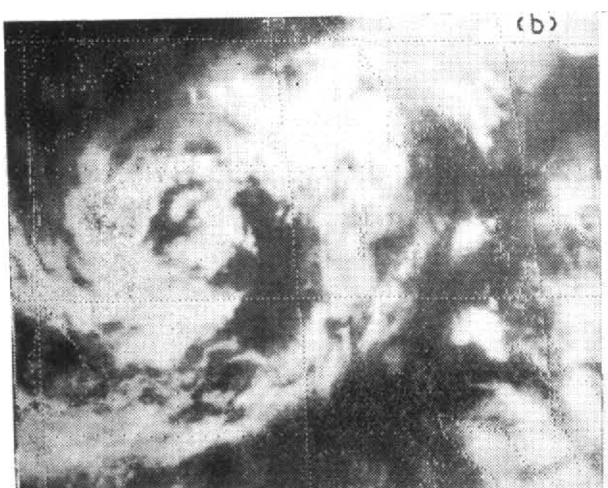


Fig. 5(b). Variability of cloud patterns (IR) associated with marginal cyclones at 15 GMT of 15 November 1985

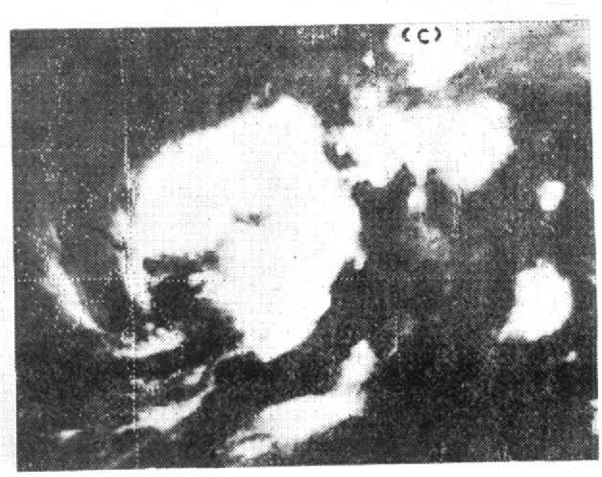


Fig. 5(c). Variability of cloud patterns (IR) associated with marginal cyclone at 21 GMT of 15 November 1985 necessary ingredient for the development of tropical disturbances. According to him the release of energy for the typhoon is through a baroclinic process wherein the cold air sinks very close to the centre of the tropical vortex and forces convergence into the cyclonic circulation. Riehl has shown and documented many case studies leading to the development of cyclonic storm through such a process. However, in exceptional cases such a development may also occur during monsoon period under favourable conditions. Mishra and Singh (1977) have also shown intensification of a depression over land into a cyclonic storm under the influence of upper tropospheric troughs which caused sinking of cold air in the vicinity of depression centre.

This was the case of the depression which formed over the Bay of Bengal on 8 September 1970 and crossed West Bengal coast on the evening of 9th. It progressively intensified into a cyclonic storm over land (Fig. 3). This intensification was the result of its interaction with two troughs in westerlies. As reported by Mishra and Singh (1977) there was incursion of cold northerly air above 850 mb. As a result temperatures fell in the depression field by 6°C at 500 mb level and by 4°C at higher levels up to 200 mb on 11th. Under the influence of the second trough the temperatures fell by 4°C at 700 and 500 mb and by smaller amounts at higher levels on 13th. These cold air advections in the middle and upper atmosphere sharpen the convective instability which lead to development of convective clouds to the west of the centre of the depression during the period 8-13 September 1970. These are seen at R & S in Figs. 3(a) and 3(b). These convective clouds are not seen on 14 September (Fig. 3c) when the intensity of the, disturbance seems to have peaked at T 4.5. It is presumed that the cold air advections brought cold air pools in the neighbourhood of the disturbance which finally collapsed to force inflow into the depression increasing its kinetic energy. Such type of interactions are not infrequent and have also taken place recently in August 1985. A detailed study is in the offing for the August 1985 case and will be published separately.

4. Intensification with landfall

A few disturbances have been seen to intensify just before landfall. Careful tracking and monitoring of cyclonic storms have revealed that a few of them have indeed intensified before their landfall.

At least three such disturbances were seen in the recent past, the intensification of two of them occurred in 1985. The severe cyclonic storm which crossed Bangladesh on 24 May 1985, maintained its intensity at T 3.0 (maximum sustained wind speed of 45 kt) for nearly 36 hours before landfall. However, at the time of landfall its intensity exceeded T 4.0. This is shown in Fig. 4 which gives us satellite imagery corresponding to 21 GMT of 24 May 1985. The curved band started developing after 12 GMT when the storm was heading towards Bangladesh coast and before that no consistent organisation and intensification trend could be seen for more than 24 hours. It caught Bangladesh almost unaware and there was huge loss of life and property. Another similar intensification took place on 15 October 1985 (figure not shown). Comparison with earlier picture showed that the organisation of the tropical cyclone significantly improved after crossing the coast. There are other cases of intensification of the tropical cyclones as a result of their interaction with the land. These are not covered here for want of space.

It is difficult to identify the forcing for this kind of intensification of tropical disturbances which solely depend on the release of latent heat from the condensation of convective clouds which are maintained by the latent heat fluxes through a deep layer of inflow. There are two possible reasons for this intensification, *viz.*, interaction with the mid-latitude westerly troughs and the increase in the boundary layer convergence without reducing evaporative fluxes. It is difficult to establish these aspects for want of proper data over these areas. Tuleya and Kurihara (1978) have shown in their numerical study that when we increase surface roughness without loss of evaporation, it leads to increase in the tropical storm intensity and almost all the storms on making landfall show a temporary increase in rainfall. This is because of the increase in the boundary layer friction which leads to increase of convection. The rainfall ceases shortly afterwards as the convection dries out the boundary layer very fast.

5. Difficulties in the tropical cyclone intensity analysis

There is no tropical cyclone analyst who has not highlighted the pronounced variability in the cloud organisation of a cyclone. The organisation and the extent of convection shows tremendous short period variability which is not necessarily related with large scale evolution of tropical cyclone. When the favourable intensification mechanisms are not present, the evolution is blocked and the pattern undergoes frequent changes in shape and organisation depending upon the extraneous forcings impinging on the vortex. This happened very frequently in 1985. We present the case of development of Bay cyclone (15-17 Nov' 85) to document the short period variability in pattern organisation. The disturbance developed as a curved band of deep layer convection at 0300 GMT of 15 November when its intensity was fixed at T 2.0 with centre near 12.0° N, 85.4° E. It was an early advanced pattern which could not persist and the organisation weakened after 0900 GMT (not shown for want of space). The centre could not be fixed at 1200 GMT. Fig. 5 shows the cloud imagery corresponding to 06 GMT of 15 November (VIS), 15 GMT of 15 November (IR) and 21 GMT of 15 November (IR). The convection was most pronounced east of 85° E at 06 GMT of 15 November but the intense convection shifted to west of 85° E at 15 GMT. After 1500 GMT another curved band started forming in the eastern sector whose organisation changed considerably during the course of next 12 hours. At 1600 GMT (figure not shown) the centre seems to be close to 85° E longitude or even west of it but at 2100 GMT of 15 November the deep layer curved band shows the centre to the east of 85° E. This may be diurnal oscillation in cloud structure associated with radiative cooling. But this could create confusion in the analysis.

This type of instability of the centre in the pattern organisation is most pronounced only in the case of marginal cyclones. The cyclone described reached a peak intensity of only T 2.5. According to Gray (1982) there could be storm without much penetrative convection and organisation and well organised convection in the banded form could also be seen without being classified as a depression. Generally success of the D'vorak's technique is due to its extensive use of (i) the typical climatology of cyclone development and decay, (ii) cloud bands and changes in cloud pattern from previous day, (iii) subtracting out the diurnal changes in cloudiness by evaluating satellite pictures at the same time of day and (iv) other special empirical relationships. Direct cloud band and convective depth do not correlate with the cyclone intensity at any given time. However, when one combines special cloud banding features with other known characteristics of tropical storm significantly better insights into the tropical storm intensity can be obtained.

Apart from the difficulties arising from the use of IR data because of poor resolution and constraints on identification of low clouds, problems occur when a tropical cyclone develops not in a regular and steady fashion but rather through erratic and random surges. This makes the process of interpretation of evolution of tropical cyclone one of the most difficult jobs. It is precisely because of these reasons that D'vorak has called for many constraints in his technique of tropical storm intensity analysis. Instead of one estimate which may be based on satellite image data and which he calls as DT (Data T-number meaning thereby T-number based on measurements made with the image), he calls for two more estimates which are known as PT (pattern T-number) and MET (Model Expected T-number). Based on the experience gained with interpretation of evolution of cyclonic storms, he has developed a model for tropical cyclone intensity analysis wherein all these features are duly taken into consideration while monitoring the intensity of tropical disturbance. The technique deals effectively with the short period changes and brings out only that which is representative of cyclone scale intensity. Therefore, the rapid changes observed in the earlier stages of evolution on a short period basis can be misleading and should be overlooked. All the constraints of the technique must be taken into consideration for an appropriate and effective monitoring of evolution of tropical cyclone.

6. Conclusions

(i) The vertical wind shear that restricts the growth of tropical vortex to the stage of marginal cyclone manifests itself in the easily recognisable shear pattern in the satellite imagery.

(ii) Intensification of these cyclones as a result of interaction with westerly troughs and temporary intensification at the time of landfall can also be monitored with satellite imagery.

(iii) Sometimes tremendous difficulties are experienced in the analysis of marginal cylones from the satellite imagery.

Acknowledgement

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